WORKING DRAFT

Rock Slope Hazard Rating Procedure

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SOIL MECHANICS BUREAU
TECHNICAL SERVICES DIVISION
NEW YORK STATE DEPARTMENT OF TRANSPORTATION

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I. INTRODUCTION

In the winter of 1988, each NYSDOT resident maintenance engineer was asked to send the Soil Mechanics Bureau a list of rock-slope locations in his area of responsibility that might conceivably be considered potential rock-fall problem sites, screening them by the following criteria (in order of importance):

1. Areas with rock-fall histories,
2. Posted rock-fall zones,
3. Obviously unstable rock masses,
4. Overhanging rocks,
5. Highly fractured and jointed oversteepened slopes (those higher than the setback from the shoulder edge),
6. Areas of ice buildup on slopes,
7. Fallen rock in ditches,
8. New cracks or gaps in the rock,
9. Areas with soil deltas at the toe of the rock slope, and
10. Rock slabs on slopes inclined toward the roadway.

The result was identification of 1741 sites. Geologists of the Soil Mechanics Bureau evaluated them using an initial rating system based on a procedure originally developed for FHWA by Duncan C. Wyllie of the geotechnical consulting firm of Golder Associates. This procedure was considered state-of-the-art at the time, and was included in FHWA's Rock Slopes manual (1). Although the Department used this system in establishing a rock-slope ranking, no implementation policy was established. Also, identification of potential rock-fall sites is an open-ended process, since sites may be added at any time.

NYSDOT has now devised a system believed to have these distinct advantages:

- It isolates three components of a possible rock fall-vehicle accident as independent factors,

- o It more objectively addresses the question of how much risk is associated with a falling rock hitting a vehicle, as well as the risk of a vehicle hitting a fallen rock, and
- o It considers not only risk posed by an existing rock slope, but level of risk that would remain after remediation.

This proposed rating procedure for rock slope hazards was presented to the Assistant Commissioner and Chief Engineer of the Office of Engineering, and approved on December 18, 1991.

II. HAZARD RATING PROCEDURE

This procedure outlines the creation of "factors" -- geologic, section, and human exposure -- for computing relative probability of a rockfall accident occurring at each site listed in the statewide rock-slope inventory. The product of these factors is defined as "relative risk."

This risk assessment model compares relative -- not absolute -- risk of rockfall accidents occurring along various rock slopes adjoining state highways. That is, the values created by this model do not actually establish how much risk is posed at a particular site, but indicate only whether risk at any rock slope is more or less than posed by other slopes.

The rating system does not indicate risks associated with rock slopes as roadside hazards, nor does it provide a means of comparing risks posed by rockfalls with other dangers to traffic. It does not consider possible catastrophic slope failures; when predictable, those situations are addressed and treated with appropriate urgency.

A. Risk Assessment Model

The following rating procedure has been developed to establish appropriate relationships among three separate factors in comparative risk assessment of accidents caused by rockfalls:

1. Geologic properties of the rock slope,
2. Ditch configurations and slope setback from the pavement edge, and
3. Traffic volume and stopping-sight distance on the highway approaching the site.

The following analysis of relative risk to the public at any particular rock slope site is based on the concept that geologic, cross-sectional, and traffic-related factors at a particular site can create or reduce risk, and that each is independent of the others. The factors can be combined (multiplied) to create a number representing relative risk of a rockfall causing a vehicular accident at each rock slope on the statewide inventory.

For the following discussion, these factors are defined as follows:

1. Geologic Factor (GF)

   This number represents risk of rock(s) falling, based on the slope's specific geologic and physical characteristics.

2. Section Factor (SF)

   This number represents risk of fallen rocks reaching travel lanes of the highway (or spilling beyond it and landing on some other occupied or otherwise sensitive location). It is related to ditch and shoulder geometry and to slope setback.

3. Human Exposure Factor (HEF)

   This number represents risk of a traffic accident occurring, given that a rockfall occurs and rock lands on the roadway.

Numerical values for these factors are established by the newly defined procedures. Definitions and procedures to be used in establishing them are as follows:

1. Geologic Factor (GF)

   A factor is needed representing risk of a consequential rockfall occurring. "Consequential"' means one of a size that may reasonably be expected to cause personal injury if it reaches the pavement, landing on or in front of an approaching vehicle, pedestrian, bicyclist, or other human presence.

   The numerical value for GF consists of the sum of points assigned to each of the following categories divided by 10, with each category scored on a scale ranging from 1 to 81 (or higher if warranted):

   o Geology of fractures in the rock structure,

   o Geology of bedding planes,

   o Block size,

   o Rock friction,

   o Water and ice conditions,

   o Rockfall history, and

   o Condition of the backslope above the rock cut.

   The sum is divided by 10 only to bring the order of magnitude of this factor into line with numerical values of both the Section Factor and Human Exposure Factor.

2. <u>Section Factor (SF)</u>

This represents the risk that fallen rock(s) would actually reach the pavement, by comparing actual ditch geometry and slope setback with the widely accepted "Ritchie Ditch Criteria" (Fig. 1). A ditch geometry meeting these criteria will prevent, with about 95-percent probability, the rockfall from reaching the pavement (1).

SF is computed as the ratio of the required Ritchie criteria to actual dimensions, yielding a number representing the risk that a rock, if it falls, will reach the pavement. The SF numerical value is computed as follows:

$$SF = (DR + WR)/(DA + WA)$$

where DR = ditch depth in feet (from the Ritchie graph),

WR = ditch width ~~depth~~ in feet (from the Ritchie graph),

DA = actual ditch depth in feet, measured in the field, and

WA = actual setback distance in feet, from the toe of the rock slope to the pavement edge of the travel lane (minimum value of 3 ft).

This numerical value ranges from 1 or less in the best circumstances, to about 11 in the worst such as a curbed section with a high rock slope immediately adjoining the curb. The Ritchie criteria do not take massive rockfalls into consideration; a voluminous rockfall could overfill a ditch meeting ideal Ritchie criteria.

3. <u>Human Exposure Factor (HEF)</u>

If rock does fall and lands on the roadway, a vehicle is threatened with impact by two separate possibilities: 1) the rock, in falling, will hit a vehicle or land so close to an approaching vehicle that it runs into the rock, or 2) the vehicle will hit a previously fallen rock that has come to rest on the roadway. The rock in the first situation may be considered to be in an "active" condition, because it is falling as the vehicle approaches or passes under the point of impact. The second situation could be termed a "passive" condition, because the rock has landed before the vehicle approaches, and is then hit by it.

a. Active Condition

This is defined as the situation occurring when the approaching driver either has no perception of the rock falling, or perceives it only as being in the process of falling. This differs from the passive condition in that the rockfall must occur when a vehicle is within a specific approach distance to the rockfall zone.

Figure 1. Ritchie ditch criteria [Figure 12.10 from Golder Associates Rock Slopes manual (1)]. For example, for a 50-ft high, 3V/1H cut slope (71.6° slope angle), the Ritchie criteria would call for a 6-ft deep, 18-ft wide ditch.

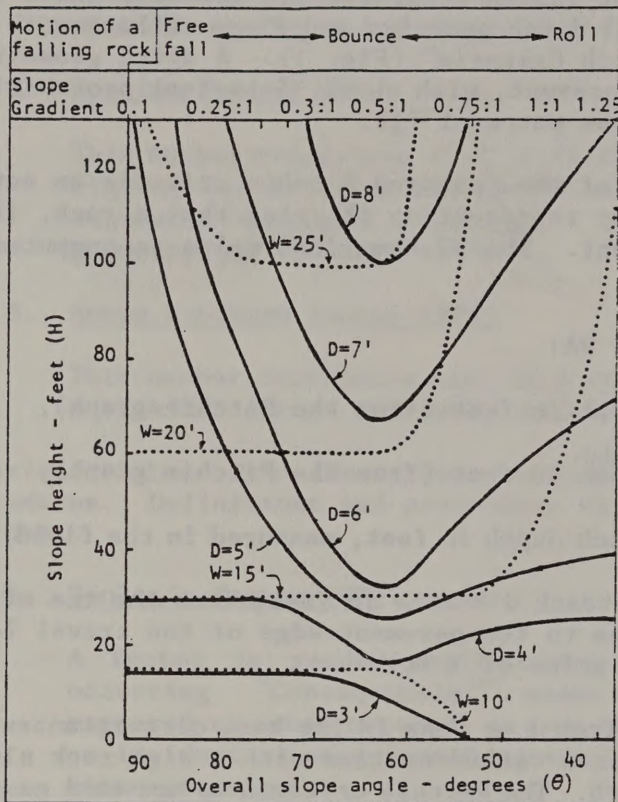


Figure 12.10(a): Ditch design chart.

Slope Gradient Conversion Table

ANGLE	VERTICAL	HORIZONTAL
5° 43'	1	10
6° 20'	1	9
7° 08'	1	8
8° 08'	1	7
9° 28'	1	6
11° 19'	1	5
14° 02'	1	4
18° 26'	1	3
19° 58'	1	2.75
21° 48'	1	2.5
23° 58'	1	2.25
26° 34'	1	2
29° 45'	1	1.75
33° 41'	1	1.5
38° 40'	1	1.25
45° 00'	1	1
51° 20'	1.25	1
56° 19'	1.5	1
60° 15'	1.75	1
63° 26'	2	1
66° 02'	2.25	1
68° 12'	2.5	1
70° 02'	2.75	1
71° 34'	3	1
75° 58'	4	1
78° 41'	5	1
80° 32'	6	1
81° 52'	7	1
82° 52'	8	1
83° 40'	9	1
84° 17'	10	1

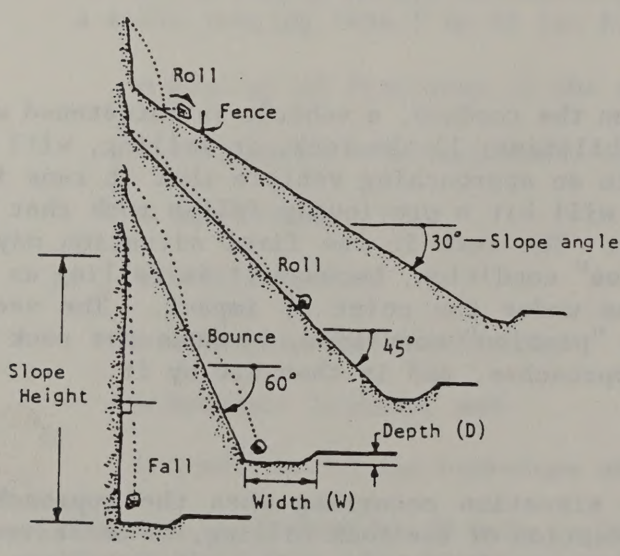


Figure 12.10(b): Rock falls on slopes.

The active condition has been analyzed by considering two possible cases. The first is where a vehicle approaches a rockfall site as a rock is falling; the driver does not see it and continues traveling without trying to stop or slow down. In the second, a driver upon approaching a rockfall perceives it occurring, but is unable to stop the vehicle in time to avoid a collision.

It can be demonstrated mathematically (Appendix A) that for these two active-condition cases, the probability of a vehicle being hit by a falling rock or running into one can be expressed by these equations:

Case 1

$$P = (AADT)(L + SSD)/(V \times 126{,}720)$$

Case 2

$$P = (AADT)\,\frac{2.5 + [1.3636\ (SSD - 3.66V)]/V}{86{,}400}$$

where L = length of rockfall zone in feet,

V = travel speed in mph,

SSD = required stopping sight distance (from AASHTO Table III-1) in feet, and

AADT = average annual daily traffic (two-way for two-lane undivided highways, or one-way for divided highways).

The larger of these two probabilities should be used as the active risk value in calculating HEF.

b. Passive Condition

Here, the rockfall has occurred at some time before any vehicle approaches the rockfall zone -- fallen rock lands on the travel lanes(s) and then sometime later a vehicle approaches. It would be reasonable to expect that no accident would occur under this condition, if the highway section had adequate SSD as defined by AASHTO (Fig. 2). Where SSD is adequate through the approach to the rockfall zone, a driver could perceive the problem, react by braking, and stop the vehicle before hitting the rock. Conversely, if SSD were less than adequate, collision with the fallen rock would be likely. The governing factor in this situation is the SSD required, as compared to that available. From an engineering

Figure 2. Table III-1, "Stopping sight distance (wet pavements)" from the 1984 AASHTO Policy on Geometric Design (3).

Design Speed (mph)	Assumed Speed for Condition (mph)	Brake Reaction: Time (sec)	Brake Reaction: Distance (ft)	Coefficient of Friction f	Braking Distance on Level[a] (ft)	Stopping Sight Distance: Computed[a] (ft)	Stopping Sight Distance: Rounded for Design (ft)
20	20-20	2.5	73.3- 73.3	0.40	33.3- 33.3	106.7-106.7	125-125
25	24-25	2.5	88.0- 91.7	0.38	50.5- 54.8	138.5-146.5	150-150
30	28-30	2.5	102.7-110.0	0.35	74.7- 85.7	177.3-195.7	200-200
35	32-35	2.5	117.3-128.3	0.34	100.4-120.1	217.7-248.4	225-250
40	36-40	2.5	132.0-146.7	0.32	135.0-166.7	267.0-313.3	275-325
45	40-45	2.5	146.7-165.0	0.31	172.0-217.7	318.7-382.7	325-400
50	44-50	2.5	161.3-183.3	0.30	215.1-277.8	376.4-461.1	400-475
55	48-55	2.5	176.0-201.7	0.30	256.0-336.1	432.0-537.8	450-550
60	52-60	2.5	190.7-220.0	0.29	310.8-413.8	501.5-633.8	525-650
65	55-65	2.5	201.7-238.3	0.29	347.7-485.6	549.4-724.0	550-725
70	58-70	2.5	212.7-256.7	0.28	400.5-583.3	613.1-840.0	625-850

[a]Different values for the same speed result from using unequal coefficients of friction.

viewpoint, this situation is objective for analysis purposes, because both the available and required SSDs can be confidently determined by established AASHTO methods (2).

Traffic volume (AADT) is inconsequential when determining HEF for a passive situation. The answer is a simple yes or no; if SSD is adequate, an accident will probably not occur (passively). If SSD is inadequate, an accident probably will occur when the next vehicle enters the rockfall area.

This passive condition analysis applies for a single accident, but does not necessarily represent the possibility of subsequent vehicles colliding with the first vehicle or the fallen rock. Because there appears to be no workable method of modeling risks of subsequent impacts, it is proposed (based solely on engineering judgment) that a passive risk value of 2 be used in situations having all three of the following conditions:

1. Average travel speeds of 50 mph or more,

2. SSD less than half the AASHTO Design SSD for the average travel speed, and

3. AADT over 10,000 vehicles daily (two-way volume for two-lane highways, one-way volume for divided highways).

Three probability (P) values are then possible for the passive situation:

P = 0 if SSD is adequate (meets AASHTO values),

P = 1 if SSD is not adequate, or

P = 2 if average travel speed is 50 mph or more, <u>and</u> SSD is less than half the required SSD, <u>and</u> AADT exceeds 10,000 vehicles daily.

The HEF number is then defined as the sum of the active and passive risk values, representing total relative probability of an accident occurring if a consequential rockfall reaches the highway, or

$$HEF = P_{active} + P_{passive}$$

These values may exceed 1 because they reflect the possibility of more than one vehicle being involved in a rockfall accident, and because two independent modes are being considered. (The worst case is where a vehicle runs into a previously fallen rock, just as another rock lands on the same vehicle.)

The following information is needed to compute HEF values for each of the rock slope sites:

- <u>Average Travel Speed</u>: this could be approximated at three or four levels -- such as 55, 45, and 30 mph -- based on field observations and posted speeds. A margin of ±5 mph or more would be acceptable. This value will be established by the regional staff.

- <u>AADT</u>: these values are readily available.

- <u>SSD</u>: actual limiting SSD must be measured (in the field) for each site. Record plan information does not suffice, because in many instances horizontal sight distance will control.

4. Relative Risk

The risk of an accident occurring at a rock slope site can now be established by multiplying the sites GF and SF by its HEF, yielding a numerical value:

$$\text{Relative Risk} = \text{Geologic Factor} \times \text{Section Factor} \times \text{Human Exposure Factor}$$

B. <u>Assumptions and Limitations</u>

Several assumptions and simplifications have been made in this analysis. Raters should be aware of them, and gage the resulting effects on ratings computed for real-world situations.

First, the analysis assumes that falling rock will land on both travel lanes of a two-lane, two-way highway, or across all lanes in one direction on a multi-lane divided highway. If in the latter case a rock fall does not land across all the lanes, the analysis model would be faulty because traffic volume is being assumed

equally distributed over all lanes. Simply assuming that the rockfall would in all cases extend across all travel lanes probably induces less error, and is certainly less complicated than analyzing the probability of the outer travel lanes being occupied.

It has been assumed that a driver's only evasive action would be to stop, but in some situations he/she might maneuver safely around a fallen rock. This maneuver has been ignored because swerving may be more dangerous than an ineffective attempt at stopping.

The model used to generate active and passive HEFs has been based on daylight stopping-sight conditions; headlight sight distance could be considered, but separate day and night traffic volumes are not normally available.

The rationale also assumes that severity of all rockfall accidents would be equal. No attempt was made to distinguish minor-injury situations from personal-injury or fatal accidents. The likelihood of serious personal injury or fatality is taken to be equal at all rockfall locations.

Catastrophic slope failure, where an entire slope might fall and cover the highway, is not modeled in this procedure. Where a massive failure is predicted, the Department would take immediate action.

C. Risk Reduction

Computation of relative risk for a rock slope has just been described. The resulting values are useful in gaging the risk posed by one rock slope as compared to others, but of limited value as a decision tool when addressing the issue of what the benefit might be of undertaking a specific treatment at a site. For that purpose, the concept of "risk reduction" is more useful, defined as the benefit provided by one of several possible treatments applicable to a given rock slope. If the amount of relative risk expected after a slope is treated is called "residual risk," then

$$\text{Risk Reduction} = \text{Relative Risk} - \text{Residual Risk}$$

A residual risk target value can be computed by recalculating relative risk, based on GFs, SFs, and HEFs associated with a recut slope meeting the Ritchie ditch criteria. This level of remediation can be viewed as the "optimum" residual risk. Improvement of residual risk beneath this optimum value would be impractical in most cases, unless the slope were completely removed or the highway relocated. Optimum risk value should not be treated as a goal that must be achieved, but as a gage of what can be accomplished. Other remedial treatments -- such as rock scaling, rock bolting, use of a rock catch fence, etc -- will result in some risk reduction.

III. FIELD EVALUATION

All sites in the inventory and any subsequently identified will be rated according to the new procedure. Appendix B is a working draft of the field manual.

Prime responsibility for rating sites lies with engineering geologists in the Soil Mechanics Bureau. A site selected for re-evaluation will be inspected by a team including Soil Mechanics Bureau engineering geologists and the regional engineering staff. The first step will be determining if the site should actually be considered "significant." This will be based on determination by the engineering geologists as to whether a rockfall could reasonably be expected to land on the pavement (travel lane), based on the SF criteria presented earlier and on judgment by the raters. If the rockfall is found unlikely to reach the pavement, the site would be deemed "not significant."

If deemed significant, the rating team will obtain all field data needed to compute relative risk. While at the site, they will also establish what specific remedial treatments are applicable. Data will be obtained as needed to compute residual risk associated with each applicable treatment. In addition, the Soil Mechanics Bureau staff will estimate quantities for slope-remediation components of each applicable treatment, and the regional staff will estimate quantities of non-rock-slope components (traffic maintenance and protection, highway work, right-of-way) associated with each treatment. The Regional Soils Engineer will be responsible for coordinating all required input. When necessary, the Region will provide proper work-zone safety equipment and/or personnel to protect the field evaluators.

The Soil Mechanics Bureau will use data from the field, along with current traffic volumes supplied by the regions, to compute relative risk at each significant site, and also to compute risk reductions provided by remediation treatment(s). These values will be submitted to the regions for review, providing them an opportunity to modify relative risk values for sites having special or unique circumstances relating to human exposure. This will allow consideration of conditions not reflected in the model presented earlier in Chapter II, and might include the following:

- High volumes of pedestrian or bicycle traffic exposed to a rockfall hazard,
- Essential, high-volume highway facilities where a detour might present more risk than the disruption caused by a rockfall, or
- Occupied dwellings/buildings or other public facilities exposed to risk.

Where such situations exist, relative risk may be subjectively adjusted at the Regional Director's discretion. In such cases, the Region will document the facts and reasons for the adjustment.

IV. DATABASE AND REPORTING

A. <u>Computer System and Database</u>

The database listing of all required data will be maintained at one central location -- the Engineering Geology Section (called "Geology" here for brevity) of the Soil Mechanics Bureau, who will have prime control and full responsibility for integrity of the data and the system.

1. Current Operations

   Geology will obtain, input, and update data, including site description, geological rating, contract work history, and maintenance work history. The Region will provide records of maintenance, where applicable, to Geology through the Regional Soils Engineer. Reports containing rock slope information may be obtained by any requesting group, the point of contact for all regional groups being the Regional Soils Engineer, who in turn will request data from Geology. Main Office groups may obtain reports through the Highway Design and Construction Section of the Soil Mechanics Bureau.

2. Future Operations

   Eventually, the Geology computer will be tied in to the mainframe computer, allowing direct access for each region. Through the Regional Soils Engineer, regions will be able to access, input, and obtain reports from the mainframe through their computers. Only Geology will be able to change hazard rating information. Both the regions and Geology will be able to update information. Remedial work records -- both contract and maintenance -- will be updated by the regions.

B. <u>Reports</u>

These will be accessible in many formats, the choices including specific rock slope site data sheets, dates last inspected, and the following listings:

1. <u>By Location</u>: region or statewide, county, residency, and route.

2. <u>By Programming Option</u>: relative risk, residual risk, risk reduction (relative risk minus residual risk), and benefit/cost ratio (risk reduction divided by estimated cost).

V. PROGRAMMING OPTIONS

No specific guidelines are proposed in this procedure regarding exact criteria for regional decision-makers in programming rock slope remediation. Instead, various strategies are outlined, and the role of decision tools presented in Chapter II is explained. Ability to quantify risk reduction facilitates establishing goals. A region could base programming decisions on a goal of reducing rockfall risk by a certain amount over some period of years. Five possible programming strategies are suggested:

1. Target the Highest Relative Risk

   This would give highest priority for repair to rock slopes presenting most risk, without considering cost of remediation, risk reduction, or cumulative risk of other rock slopes.

2. Target the Greatest Risk Reduction

   This would give highest priority to sites where the greatest amount of risk can be eliminated. In many cases, this may give a ranking identical or similar to that based on relative risk. Sites would be ranked on the basis of the greatest risk being eliminated. Costs of remediation and cumulative risk reduction of other rock slopes would not be considered.

3. Target the Greatest Risk Reduction per Unit Cost

   This would base decisions on eliminating the greatest amount of rockfall risk at any funding level. Sites would be ranked by benefit/cost of remediation. (Regions can estimate cost of remediation based on quantities estimated by the rating teams. Sites with highest relative risk might not have highest priority.)

4. Combine Rock Remediation with Other Highway Work

   This would allow decision-makers to examine risk levels of all significant sites within their region, and judge whether to include rock slope remediation in some future highway project containing the site, saving the cost of administering a separate smaller project.

5. Group Locations

   This can be advantageous where several separate sites are within a given geographic area. When these are combined as one project, lower unit costs can usually be obtained.

In the future, relative risk values generated by this rating procedure may also be used to gage when other actions are appropriate. Ranges of relative risk values may be established that correspond to various actions, such as:

- o Doing nothing.
- o Monitoring visually by maintenance patrols.
- o Re-inspecting by geologists at various intervals.
- o Monitoring with instrumentation.
- o Repairing by contract 1) immediately, 2) by special contract, 3) by combining with the next scheduled contract, or 4) by inclusion in the five-year program.
- o Closing the highway intermittently or until repaired.

Some of these actions may not be necessary or appropriate. This topic should be the subject of a follow-up study after the new rating system has been implemented statewide.

VI. UPDATING THE DATABASE

To meet program objectives, existing data must be updated periodically, with information originating from the regions or the Soil Mechanics Bureau.

The regions may add new slopes to the program at any time by notifying the Soil Mechanics Bureau. Adding a slope will prompt Geology to perform a rating. Any remedial work to slopes already in the program -- by construction contract, maintenance contract, or maintenance forces -- should be recorded by the Region and reported to Soil Mechanics through the Regional Soils Engineer when it is completed, triggering the re-evaluation process. Actual rockfalls of any magnitude should be reported to Soil Mechanics through the Regional Soils Engineer on proper forms for recording these events.

The Soil Mechanics Bureau will periodically update cost of work and traffic information, the database then being revised to reflect the new information on a continuing basis.

REFERENCES

1. Rock Slopes: Design, Excavation, Stabilization. Seattle: Golder Associates, May 1988 (4th ed.)

2. A Policy on Geometric Design of Highways and Streets. Washington: American Association of State Highway and Transportation Officials, 1984, pp. 158-59.

APPENDIX A. DERIVATION OF THE ACTIVE CONDITION HUMAN EXPOSURE FACTOR

APPENDIX A. DERIVATION OF THE ACTIVE CONDITION HUMAN EXPOSURE FACTOR

HEF is a measure of risk of an accident occurring if and when a rock falls and reaches the highway, and is meaningful only when probability of another action (the rock actually falling on the highway) is 1. If one selects a given 24 hr as the period of analysis, and it is known that a rockfall will occur at a given rock slope within that period, probability of the incident is 1 during that period.

The analysis can be based on the concept of the 24-hr period divided into some number N of equal time segments, such that the length of each is

$$\frac{24 \text{ hr} \times 60 \text{ min/hr} \times 60 \text{ sec/min}}{N} = 86{,}400/N \text{ (sec)}.$$

An accident will occur if rock falls during the same one of the N time segments during which a vehicle also approaches or is under the rock slope. To establish N two cases must be explored:

<u>Case 1</u>

First, if a vehicle approaches a rockfall site and rock is falling, the driver might not see it and continue through the approach and beneath the rock without stopping or slowing down. The vehicle enters the zone beneath the rockfall at normal travel speed V(mph), and continues through the length of the rockfall until rock lands on it. If the zone is defined by some length L(ft), and the approach is of some length D, the minimum time T(sec) of each of the N time segments would be

$$T = \frac{L(\text{ft}) + D(\text{ft}) \times 1 \text{ mph}}{V(\text{mph}) \times 1.4667 \text{ fps}}$$

where 1 mph = 1.4667 fps.

The probability P of an accident occurring in the 24-hour period, if only one vehicle passes the rockfall zone, would then be:

$$P = \frac{T(\text{sec})}{86{,}400(\text{sec})}$$

$$= \frac{L + D(\text{ft})}{V(\text{mph}) \times 1.4667 \times 86{,}400}$$

$$= \frac{L + D(\text{ft})}{V(\text{mph}) \times 126{,}720}$$

It is proposed that approach distance D be taken as the AASHTO required stopping distance for travel speed V(mph), because if it were longer than this normal stopping distance, the driver could probably stop before reaching the rockfall. This probability would then become

$$P = \frac{SSD + L}{V(mph) \times 126{,}720)}$$

where SSD = available stopping sight distance, and

L = length of rockfall zone in feet.

Case 2

The other case needing analysis would be where a driver, approaching the rockfall zone, sees it occurring and can stop the vehicle. A different set of N time segments is associated with this action, based on time needed to react and stop. AASHTO criteria generally provide that 2.5 sec are needed for perception/reaction. Once brakes are applied, assuming constant deceleration over a distance S(ft), time needed to stop is

2 x S/Initial Speed.

Length T of the time segment N under consideration is then

$$T = 2.5 \text{ sec} + \frac{2 \times S}{V}$$

where S = braking distance in feet (from AASHTO Table III-1), and

V = initial travel speed in mph.

S can be solved in terms of required stopping sight distance SSD:

$$S = SSD(ft) - 2.5\ V(mph) \times \frac{1.4667 \text{ fps}}{1 \text{ mph}}$$

$$= SSD - 3.667\ V(ft)$$

Deceleration time can then be expressed as

$$\frac{2 \times (SSD - 3.6667\ V)}{V(mph) \times (1.4667 \text{ fps}/1 \text{ mph})}$$

The total time segment is then perception/reaction time plus braking time, or

$$T = 2.5 \text{ sec} + \frac{2(SSD - 3.6667\ V)}{V(1.4667 \text{ fps/mph})}$$

Risk of an accident occurring if one vehicle is traveling this highway during the 24-hr analysis period would be

$$P = \frac{2.5 + 2(SSD - 3.667V)/V \times 1.4667 \text{ fps/mph}}{86{,}400(\text{sec})}$$

$$= \frac{2.5 + [1.3636(SSD - 3.667V)]/V}{86{,}400}$$

where V = travel speed in mph,

SSD = required stopping sight distance in feet (from AASHTO Table III-1),

1 mph/sec = 1.4667 fps, and

Driver Reaction Time = 2.5 sec

It can be shown that except for longer falling rock zones, the Case 2 situation generates higher risk than the Case 1 situation. For example, at 55 mph L must exceed 348 ft for the Case 1 equation to govern. At 40 mph L must exceed 367 ft and at 30 mph be longer than 332 ft, for the Case 1 probability to be higher than that of the Case 2 probability. The Case 1 formula thus applies only in situations where rockfall zones are likely to be longer than 350 ft.

These formulas can be modified to reflect probability of vehicular impact in a highway section having (instead of one vehicle daily) a traffic volume equal to the AADT, by multiplying the AADT value by the probability of an impact if AADT were 1. (AADT should be the two-way value for two-lane undivided highways, or the one-way value for divided highways.)

<u>Case 1</u>

$$P = (AADT)(L + SSD)/(V \times 126{,}720)$$

<u>Case 2</u>

$$P = (AADT)\ \frac{2.5 + [1.3636(SSD - 3.667V)]/V}{86{,}400}$$

APPENDIX B. ROCK SLOPE HAZARD RATING PROCEDURE: FIELD MANUAL (WORKING DRAFT)

INTRODUCTION

This manual establishes a uniform statewide procedure for obtaining field information required to determine relative risk of a rock falling from a slope, reaching the pavement, and hitting or being struck by a vehicle. Relative risk is defined as equal to the product of the Geologic Factor multiplied by the Section Factor multiplied by the Human Exposure Factor, all of which are explained here. All three factors require field observation or measurement which are described here in detail. The data should be recorded on Form DH-1, included at the end of this manual. In addition, possible remedial treatments must be determined while in the field. The generally acceptable treatments are covered in this manual. All field inspections must be made in the company of the designated Regional representative.

SAFETY

The rock slope rating survey takes place in potentially hazardous locations. Dense, high-speed traffic areas are particularly dangerous. Consequently, attention to safety is paramount. Rock slope evaluators should assess the risks and consult with the appropriate Regional Safety Coordinator to plan and arrange backup support where necessary.

Soil Mechanics Bureau employees often must work close to vehicular traffic. In some instances their work involves long-term operations, and Highway Maintenance forces should establish work zone protection. At other times, they work at the side of the road for short periods, but these can be equally dangerous. Because the work is of brief duration and the crew may consist of only a few inspectors traveling in a passenger vehicle, it is not practical or possible to set up a signed work zone as in maintenance operations. Nevertheless, several guidelines should be followed to ensure safety of employees working on highways for short periods.

If work or inspection is to be completed on the shoulder or in an area adjoining the highway, pull the vehicle as far off the road as possible and turn on the four-way flashers. If it is necessary to be on the shoulder, station a lookout facing traffic to warn co-workers of oncoming traffic. It may be advantageous, in certain instances, to carry several traffic cones to place around the car on the shoulder to make the traveling public more wary and alert.

If an inspection is to be conducted in the traffic lane, extreme caution must be used. A flagger should be stationed a substantial distance preceding the operation. The flagger's location should be based on sight distance, speed limit, traffic volume, road conditions, type of work, and the obstacle that the work presents. The flagger should be alert at all times and on his/her feet facing oncoming traffic.

Refer to Section 350 of the MUTCD for specific information on work zone protection and traffic control procedures.

Flagging Procedures

A flagger has four basic directions to communicate to drivers: to stop, to slow down, to proceed, and to change lanes.

To Stop: The flagger must hold the flag, fully extended, out in front of oncoming traffic, at a level low enough to permit him/her to see over the flag. He/she should show the flag with enough advance warning to allow the approaching motorist(s) ample time to react appropriately and safely. The flag should be held motionless, not waved, raised, or lowered.

To Proceed: After the drive has stopped and it is safe to allow him/her to proceed, the flagger should completely remove the flag from view, motion traffic ahead with the free hand and arm, and not wave traffic ahead with the flag.

To Slow Down: If a flag is used, it should be kept at the flagger's side out of sight. The flagger should slowly raise and lower his free hand with the palm down. If a paddle is used, the "slow" face must be plainly visible to approaching traffic. He/she may also wish to emphasize the need to slow down by raising and lowering his free hand.

To Change Lanes: The flagger should motion oncoming traffic slowly, with the free hand and arm moving in the desired direction away from the body. He/she may also point in that direction.

Another method of ensuring safety of working employees is blocking the traffic lane with the vehicle and turning on its four-way flashers. This may be used in conjunction with a flagger and provides a protective barrier between the workers and oncoming drivers. This method should not be used unless minimum requirements set forth in the MUTCD can be met with regard to signing, coning, and other traffic control devices.

While working within the highway right-of-way, a worker must wear an approved hard hat and an approved vest, shirt, or jacket. Without exception, flaggers must wear approved safety vests.

EQUIPMENT

1. Hard hats and vests
2. State car with bubble light (may need maintenance backup)
3. 100-ft cloth tape
4. Brunton compass
5. Inclinometer or range finder
6. Measuring wheel
7. Field rating sheets (laptop computer optional), maps, and other information
8. Clipboard
9. Camera
10. 6-in. sight distance target and 3.5-ft rod (eye height according to AASHTO Design Policy)

Figure 1. Categories for Geologic Factor

1A.	GEOLOGY (Xtal.)	Massive, no fractures dipping out of slope.	Discontinuous fractures, Random orientation	Fractures that form wedges	Discontinuous fractures dipping out of slope	Continuous fractures out of slope
1B.	GEOLOGY (Sed.)	Horizontal to slightly dipping.	Ravelling, Occasional small blocks.	Small overhangs or columns, Numerous small blocks.	Overhangs, Some large unstable blocks, High columns	Bedding or joints dipping out of slope, Over steepened cut face
2	BLOCK SIZE	6 IN.	6 TO 12 IN.	1 TO 2 FT	2 TO 5 FT	5 FT or more
3	ROCK FRICTION	Rough, irregular	Undulating	Planar	Smooth, slickensided	Clay, gouge-faulted
4	WATER/ ICE	Dry	Some seepage	Moderate seepage	High seepage/ brush	High seepage with long backslope/ brush
5	ROCK FALL	No Falls	Occasional minor falls	Occasional falls	Regular falls	Major falls/ slides
6	BACKSLOPE ABOVE CUT	Flat to gentle slope (up to 15°)	Moderate slope (15°-25°)	Steep slope (25° - 35°)	Very steep (>35°) or steep (25°-35°) with boulders	Very steep (>35°) slope with boulders

Requirement:

Each site must be photographed during the field evaluation.

THE GEOLOGIC FACTOR

Physical conditions directly affect stability of a rock slope. The geologic factor is determined by summation of categories numbered 1A or 1B and 2 through 6 (Fig.1). Categories are assigned 1, 3, 9, 27, or 81 points. These are the only values to be selected by the rater. No intermediate values may be used. One point is assigned to the best condition and up to 81 points to the worst. The categories are: 1A. Geology Xtal. (crystalline) or 1B Geology (sedimentary); 2. Block Size; 3. Rock Friction; 4. Water/Ice; 5. Rockfall History; and 6. Backslope Above Cut.

1A. Geology (Xtal.), Crystalline.

Stability of rock slopes composed of hard, weathered crystalline bedrock is determined mainly by the structure of discontinuities. Fractures in the rock

slope may be natural features or result from past blasting effects. Joint orientations and inclinations must be considered to assess rock slope stability. Rock slopes exhibiting mostly wedge-type failures and flat-lying or dipping into the slope should receive a rating of 9 points. A slope with a prominent joint set dipping out of slope (toward the road) with average length less than 10 ft should receive 27 points. Any slope with a prominent joint set or sets greater than 10 feet long should receive 81 points. If the crystalline rock slope contains weak weathered zones causing unstable conditions, sedimentary rock categories (1B) may be more appropriate for rating.

		1 Point	3 Points	9 Points	27 Points	81 Points
1A.	GEOLOGY (Xtal.)	Massive, no fractures dipping out of slope.	Discontinuous fractures, Random orientation	Fractures that form wedges	Discontinuous fractures dipping out of slope	Continuous fractures out of slope

1B. **Geology (Sed.), Sedimentary.**

Sedimentary rock slope stability is strongly influenced by rock type and bedding orientation. Slopes containing different stratigraphic layers may have differential weathering or erosional problems. This can lead to overhangs and unstable rock conditions on the slope. Steeply dipping beds in any orientation also may pose problems when joints and discontinuities are present. The rating for sedimentary rock slopes may be higher in points if structural conditions are considered. If structural features dominate slope stability, categories for crystalline rock slopes (1A) should be used.

		1 Point	3 Points	9 Points	27 Points	81 Points
1B.	GEOLOGY (Sed.)	Horizontal to slightly dipping.	Ravelling, Occasional small blocks.	Small overhangs or columns, Numerous small blocks.	Overhangs, Some large unstable blocks, High columns	Bedding or joints dipping out of slope, Over steepened cut face

2. **Block Size.**

Block size categories should be estimated by maximum dimension of the largest unstable blocks on the slope or the largest rocks in the ditch. Often more massively bedded solid rock slopes may receive a higher rating because the rock cut is less dissected.

		1 Point	3 Points	9 Points	27 Points	81 Points
2	BLOCK SIZE	6 IN.	6 TO 12 IN.	1 TO 2 FT	2 TO 5 FT	5 FT or more

3. Rock Friction.

This is estimated by roughness of the surface of bedding and joint planes. Slickensided, clay gouge, weathered rock, and mineralized surfaces such as a biotite or serpentine layers may increase the rockfall potential. Potential failure surfaces should be carefully inspected since many of these features may not be readily apparent.

		1 Point	3 Points	9 Points	27 Points	81 Points
3	ROCK FRICTION	Rough, irregular	Undulating	Planar	Smooth, slickensided	Clay, gouge-faulted

4. Water/Ice.

This category may fluctuate daily or seasonally, making a rating decision difficult. The slope should be examined with this variability in mind. Presence of ice and/or brush on the slope indicates a potential water problem. A long backslope will bring a large quantity of water to the slope even if none is apparent during the inspection. A rock slope cut off and isolated on all sides from higher slopes will have few water problems.

		1 Point	3 Points	9 Points	27 Points	81 Points
4	WATER/ ICE	Dry	Some seepage	Moderate seepage	High seepage/ brush	High seepage with long backslope/ brush

5. Rockfall.

This category covers the history of rockfalls at the site. Examination of the ditch will reveal past rockfalls if it has not been cleaned. Roadway and shoulder sections may also show evidence of rockfall damage. If maintenance personnel are present during the evaluation, they may provide useful historic information. The rater must use his/her best judgment as to the rockfall potential in comparison to the other rated slopes.

		1 Point	3 Points	9 Points	27 Points	81 Points
5	ROCK FALL	No Falls	Occasional minor falls	Occasional falls	Regular falls	Major falls/ slides

6. Backslope Above Cut.

This is the natural slope existing above the rock cut. It may be composed of bedrock, bedrock and soil, or soil and boulders. The backslope above the rock cut may contribute to rockfall potential. Even if no rock is in the backslope, water cascading down can contribute to instability of the rock cut. The steeper the slope, the more water and debris have potential to fall down the rock cut face.

		1 Point	3 Points	9 Points	27 Points	81 Points
6	BACKSLOPE ABOVE CUT	Flat to gentle slope (up to 15°)	Moderate slope (15°-25°)	Steep slope (25° - 35°)	Very steep (>35°) or steep (25°-35°) with boulders	Very steep (>35°) slope with boulders

THE SECTION FACTOR

To obtain this value, several field measurements are necessary:

Slope Height

Vertical slope height should be measured from the highest point from which rock is expected to fall to the pavement edge. The highest point may be part of the cut face or the natural slope. Slope height can be measured using the TOPCON range-height finder or a Brunton compass and an optical range finder. Measure the angle to the top of rock slope from the pavement edge or shoulder. Determine the angled distance to the top of the rock slope from this position using the range finder. The slope height can be computed using the following formula:

$$\text{Slope Height} = \text{Angled Distance} \times \text{Sin (top of rock slope angle)} + \text{Height of Instrument}$$

For example: given that top of rock slope = 30°, angled distance = 40 ft, and instrument height = 5.5 ft, find Slope Height (SH):

$$SH = 40 \text{ ft} \times (\sin 30°) + 5.5 \text{ ft}$$

$$= (40 \times 0.5) + 5.5$$

$$= 20 + 5.5 = 25.5 \text{ ft.}$$

Slope Angle

Existing slope angle can be measured using an inclinometer or Brunton compass. Some slopes will have sections with near-vertical slope faces and/or near-horizontal sections. The rater should stand in the ditch and incline the instrument parallel with the average overall slope inclination to measure this angle. In the case of a presplit slope, the instrument can be put up against a drill hole trace and the slope angle measured directly.

Ditch Width

This dimension is measured from the toe of the slope to the roadway edge line or pavement edge. It should be measured at the maximum slope height location. If ditch width at the maximum height of cut exceeds the approximated average ditch width, average ditch width should be recorded. This width should be determined by sighting down the length of the rock cut and approximating the distance from the average projected toe of slope to the roadway edge line.

Ditch Depth

This may vary considerably along the length of the rock cut and width of the ditch. Ditch depth should be measured at the maximum slope height location. It should be measured from the pavement edge elevation down to the bottom of ditch approximately 3 ft out from the projected toe of slope. One way to measure this is to extend a tape from the pavement edge to the toe of slope, level the tape, and measure to the bottom of ditch with a rule. Another is to hold a fixed eye height at the pavement edge with one rule and read the other rule in the ditch with a level. Subtract these two readings for the ditch depth.

Ritchie Width, Ritchie Depth

First, slope height and overall slope angle must be determined. Based on these measurements the required Ritchie width and depth can be determined using the Ritchie ditch design chart (Fig. 2). For example: 40-ft slope height at a three vertical-on- one horizontal slope angle would require a 17 ft wide by 5 ft deep ditch.

THE HUMAN EXPOSURE FACTOR

Several additional field measurements are necessary to determine the Human Exposure Factor:

Cut Length

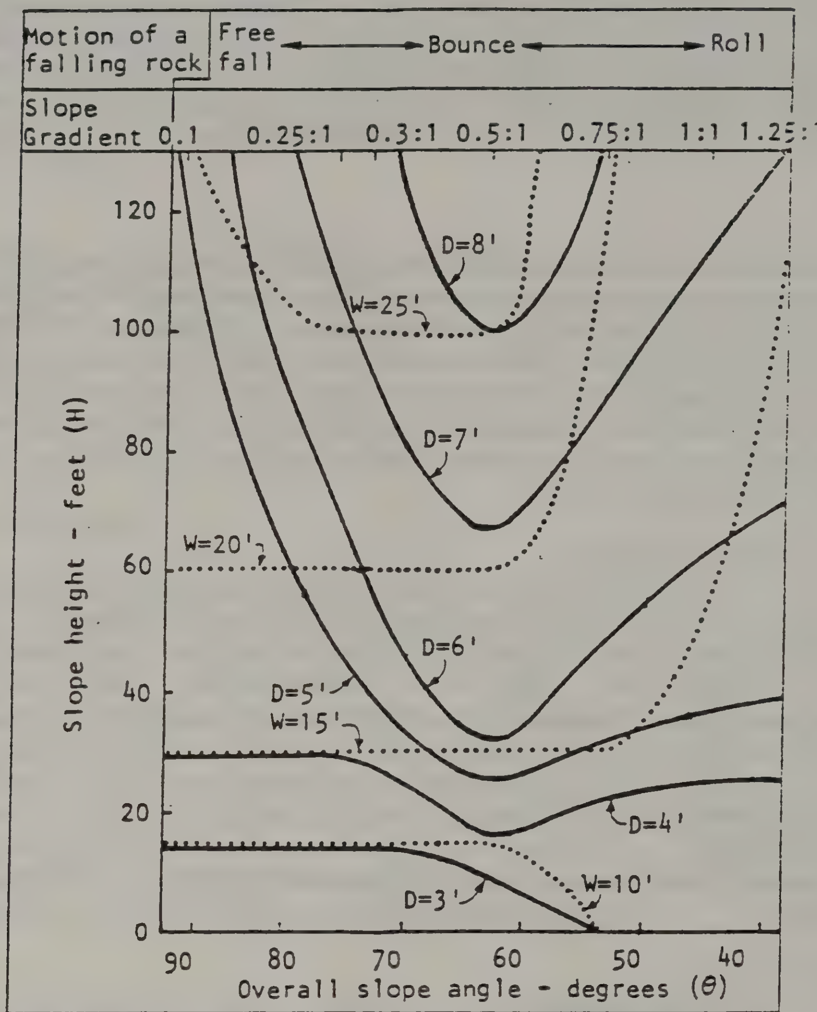
This is measured as the length of the rock cut where a rockfall might occur that could reach the pavement. Usually some sections at both ends of the cut have sufficient setback for rock slope height, according to the Ritchie Ditch Criteria. This length should not be included in the cut length, which may be determined using a measuring wheel or measuring tape.

Decision Sight Distance

This is the length of roadway where a 6-in. object located on the roadway edge line first becomes visible to the approaching driver. Sight distance along a rock cut will vary considerably, due to curves (horizontal) and rises (vertical) as well as trees, road signs, and other fixed objects.

To measure this distance according to AASHTO, a 6-in. object must be placed along the roadway edge line and sighted from the roadway centerline at an eye height of 3.5 ft. Distance to where the object disappears from sight is then measured.

Figure 2. Ditch design chart [Fig. 12.10(a) from - Rock Slopes: Design, Excavation, Stabilization prepared by Golder Associates of Seattle, Washington (4th ed., 1988) for the Federal Highway Administration, U.S. Department of Transportation].



The decision sight distance measurement requires the use of three tools:

1. A 6-in. sight distance target
2. A 3.5-ft rod
3. A measuring wheel or 100-ft cloth tape

The target is placed at the roadway edge line at the point of concern. The distance is then measured where the target cannot be seen from the roadway centerline at an eye height of 3.5 ft. Target location may have to be adjusted and measurements taken at several points along the slope before minimum distance can be determined.

This length and the factor limiting sight distance should be recorded. If sight distance is greater than 550 ft, it need not be measured but should be recorded as greater than 550 ft on the field form.

Number of Lanes

Total travel lanes in one direction adjoining to the rock slope should be recorded. These may include entrance ramps, exit ramps, or acceleration lanes, but not paved shoulders.

AASHTO Stopping Sight Distance (SSD)

Posted speed limit should be recorded on the field worksheet.

COMMON REMEDIAL TREATMENTS

The back page of the field worksheet Form No. DH-1 deals with existing rock slope problems and possible solutions. Before any remedial measures for the rock slope can be determined, existing problems at the site must be understood. Mechanics of slope failure and treatment are thoroughly analyzed in the FHWA Rock Slope Engineering Manual. Check off the most probable method of failure at the rock slope at the top of the field form.

Remedies

Some common remedies for rock slopes can be found on the field worksheet. Determine the most appropriate treatment(s) based on sound engineering judgment--a combination of two or more may be necessary. For example, a rock slope may require a recut and a fence or barrier. A recut should be considered when a slope has a high section factor and/or human exposure factor. A scaling contract for a slope with these characteristics will not reduce them and the scaled slope will still have a high rating. However, if a slope has a high rating mainly due to geologic factors, it may be a good candidate for scaling. Recutting this slope may reduce its rating little more than scaling.

After-Remediation Geologic Factors (page 1 of the field worksheet)

The new geologic factor can be estimated only after a recommended treatment for stabilization has been selected. Based on what the new "corrected" rock slope would be, a new geologic factor can be determined using the rating procedure. This number reflects the optimal geologic factor that could be economically attained. For example, recutting a slope might reduce its block size and rockfall potential categories, but might not affect the back slope.

Recut

Once it has been decided that the appropriate remedy is to recut the slope, one must determine the recut angle, recommended setback, and estimated yardage to be removed.

Angle

The recut angle should be designed at the steepest possible angle that will create a stable maintenance-free slope. Vertical rock slopes are usually not designed since motorists may see the rock cut as tilting toward the road. (Usual design rock angles are listed on the field sheet as: 3V:1H, 3V:2H, 1V:1H, 2V:1H.)

To design the slope angle, the dip angle of bedding, foliation, fractures, and joints should be measured using a Brunton compass. A stable rock slope design may match the angle of major discontinuities or bedding surfaces.

General design guidelines are as follows:

Diabase, granite: 3V:1H (3 vertical on one horizontal)
Gneiss/Westchester Co.: 3V:2H or match foliation
Horizontal bedded limestone: 3V:1H to vertical
Interbedded limestone and shales: 3V:2H
Shale: 1V:1H

Each slope should be carefully examined to determine final geometry of the site. A flatter slope or greater setback may be necessary if the top of slope is to intersect at a desirable location.

Recommended Setback:

The design setback of the slope should conform to the Ritchie ditch Guidelines as shown on the field sheet chart. The chart will give the Ritchie ditch width and depth for a given height and slope angle. The Ritchie ditch section approved by FHWA begins with the full depth at the toe of slope, a flat bottom section, and a 1-on-$1\frac{1}{4}$ horizontal slope up to the shoulder edge or pavement edge. A minimum setback for blasting should be 5 ft behind the existing toe of slope to ensure sufficient burden for blasting.

Scaling

Scaling quantities should be estimated from the amount of rock expected to be removed and not just the amount of loose rock on the slope. Removing a loose piece of rock may sometimes undermine the slope, and its upper part must be scaled further back. If blasting is required, it should be so noted.

Design of rock scaling jobs requires an estimate of rock removal quantities in cubic yards. When the entire face needs treatment, scaling volume can be roughly estimated using the following formula:

Surface area of rock cut face (ft^2) x weathering depth (ft) ÷ 27 ft^3/yd^3)

For example, given a rock slope-20 ft high and 500 ft long, with an estimated 3 ft weathering depth:

$$20 \text{ ft} \times 500 \text{ ft} = 10{,}000 \text{ ft}^2 \text{ surface area}$$
$$10{,}000 \text{ ft}^2 \times 3 \text{ ft} = 30{,}000 \text{ ft}^3 \text{ volume}$$
$$30{,}000 \text{ ft}^3 \div 27 \text{ ft}^3/\text{yd}^3 = 1{,}111 \text{ yds}$$

Note: 3 ft of weathering is an appropriate estimate for most rock slopes.

Another method of determining minor scaling amounts is estimating how many truckloads of material will be removed. Estimate 7 to 8 yds^3 per standard rock truck.

Rock Bolting

This is usually the final remedial treatment following a recut or scaling operation. Some areas may be targeted for bolting where alternative treatments would be prohibitively expensive. Rock bolts should be installed to a length of 3 ft past the weathered zone or discontinuity into "solid" rock. Block size of unstable rock must be large enough to be bolted and the rock slope composed of sufficiently competent rock to provide a suitable anchor.

Mesh

A rock mesh screen may be considered for slopes containing numerous small (6 to 10 in.) loose blocks, or where recutting or scaling is not feasible or may create right-of-way problems. Rock bolts may be installed at the top of slope to anchor the mesh and pins on a grid pattern and secure the mesh to the slope face.

Fence

Rock fence may be considered for placement at the top of slope, at a rock bench, or at an appropriate location at the toe of slope. Design of optimal height and fence location can be aided by using the Colorado Rockfall/Simulation Program (CRSP), a computer program developed by Colorado DOT. Accurate cross-sections must be taken for reliable results.

Barrier

A barrier may be considered at the edge of shoulder. It may be in addition or as an alternative to rock slope stabilization treatments. Barriers commonly considered include:

1. Earth or broken rock berm
2. Jersey barrier or barrier with fence
3. Trie-beam guiderail

Recut Yardage Estimation

The final category on the field worksheet is used to estimate the quantity of rock removed for a recut slope. Using a Brunton compass, inclinometer, and a tape, the required measurements can be completed. To estimate the existing rock slope geometry, the rater must divide the slope into sections of about equal height along measured lengths, which should reflect variations in slope dimensions. Slope height generally begins at zero and rises along a measured section length to the maximum height. This height continues for a measured section length until it drops back to zero. A slope rising to a maximum height and continuing at that height until it drops down at the other end can be measured with only one cross-section measurement. A slope with greater variability can be so estimated, but more sections will provide a more accurate estimate. At each section, existing slope angle and ditch dimensions should be recorded. Using the Ritchie ditch chart with the recut design angle and maximum projected slope height following a recut, the required Ritchie ditch can be determined. The recut slope angle and Ritchie ditch required at the maximum slope height should be maintained for the entire slope.

Form No. DH-1

SITE EVALUATION
FIELD SHEET

Date ____________________

Site # _______ Inspector _______

Rock Type __________

GEOLOGIC FACTOR

	Existing	Optimal Residual
1A	______	______
1B	______	______
2	______	______
3	______	______
4	______	______
5	______	______
6	______	______
sum	______	sum ______

SECTION FACTOR

Angled Distance ______

Distance Angle ______

Slope Height ______

Avg. Slope Angle ______

Ditch Width ______

Ditch Depth ______

Ritchie Width ______

Ritchie Ditch ______

HUMAN EXPOSURE FACTOR

Cut Length ______

Decision Sight Distance ______

# of Lanes Each Direction ______

Posted Speed Limit ______

Photo # ______

FORM NO. DH-1 CONT.

PROBLEM:

BOULDERS - ______

OVERTURNING - Isolated blocks from cut ______

Columns ______

Overhangs ______

Toppling ______

SLIDING - Plane ______

Wedge ______

REMEDY(IES):

Recut - 3/1____; 2/1______; 3/2_______; 1/1______; other______; Est.yd3______

Recommended setback ____________________________

Scale - Whole face_______; Top of cut______; Selected Areas_____; Est. Sq. Ft._____; yd^3_______

Bolt - Pattern______; Sel. Loc.______; Est. No.______; Length______; Total______;

Mesh - Loose______; Anchored_______; Est. Area ($Ft.^2$)_______

Fence -

	DECELERATE	STOP	ROWS	LENGTH(S)	HEIGHT
Unslope -					
Top of Cut -					
At Grade -					

Barriers - Loc. _______________ Length ____________________

RECUT ESTIMATE OF QUANTITY WORK SHEET

SLOPE HEIGHT	ANGLES EXT. FRONT	NEW	EXT. TOP	DITCH WIDTHS EXT.	RITCHIE	DITCH DEPTHS EXT.	RITCHIE	SECTION LENGTH